*Safety & Environmental Advantages of Using Tritium-Lean Targets for Inertial Fusion Energy**

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Abstract

While traditional inertial fusion energy (IFE) target designs typically use equimolar portions of deuterium and tritium and have areal densities (ρr) of ~ 3 g/cm^2, significant safety and environmental (S&E) advantages may be obtained through the use of high-density (ρr ~ 10 g/cm^2) targets with tritium components as low as 0.5%. Such targets would absorb much of the neutron energy within the target and could be self-sufficient from a tritium breeding point of view. Tritium self-sufficiency within the target would free target chamber designers from the need to use lithium-bearing blanket materials, while low inventories within each target would translate into low inventories in target fabrication facilities. Although past work found such designs to be impractical due to the large driver energies that would be needed to attain such high densities, recent work suggests that a fast igniter technique may make such concepts viable at total driver energies of ~ 7-10 MJ.[1-6] Additionally, ongoing target designwork may increase coupling efficiencies to > 25% and further reduce required driver energies to 4-5 MJ.[7] The absorption of much of the neutron energy within the target and the extremely low tritium inventories make "tritium-lean" targets appear quite attractive from an S&E perspective.

Overview of Tritium-Lean Concept

- "Traditional" IFE target designs use a 50/50 mix of D-T fuel and have ρr ~ 3 g/cm^2
- Tritium-lean target features only 0.5% T and a large ρr of 16.8 g/cm^2
- Past work found tritium-lean designs unattractive due to need for large (> 10 MJ) drivers
- Targets might be driven at 4-5 MJ using a fast igniter concept[4-6]:
  - Internal energy = 1.15 MJ/Coupling efficiency of 25% assumed
  - Large targets (~ 20 mg) are required
  - Large yields (1.33 GJ) result
- Tritium-lean target gets its yield from combination of fusion reactions[5]:
  - 60.5% D-D (23.9% of energy)
  - 28.8% D-T (54.7% of energy)
  - 10.7% D-^{3}He (21.4% of energy)
- Large ρr results in scattering within the target and significant softening of the neutron spectrum:
  - 68% of source energy is trapped in target
  - Radiation damage to first wall is reduced
  - Target is self-sufficient from tritium breeding perspective

A power plant utilizing tritium-lean targets might have a tritium inventory 100´ less than a traditional D-T power plant and designers may be able to avoid lithium-bearing materials in the blanket.

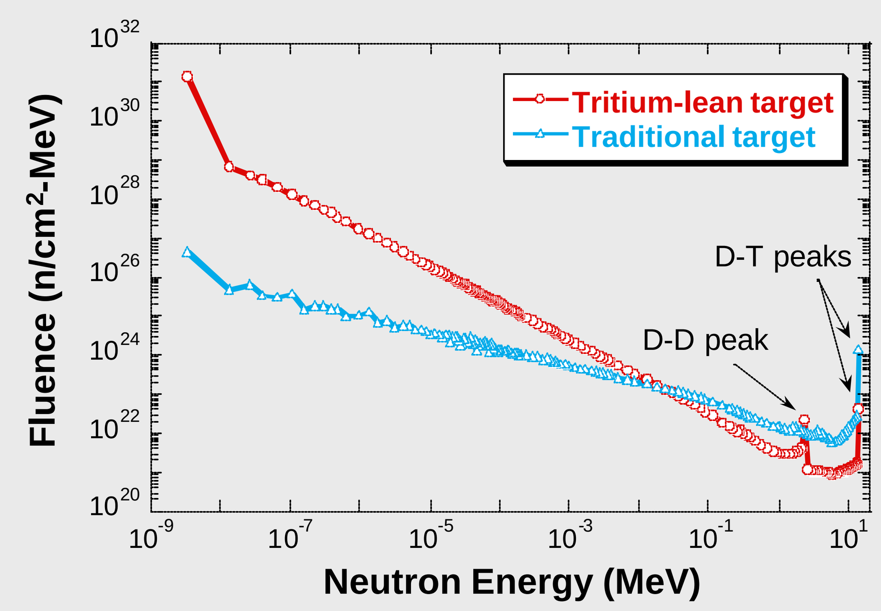
Tritium Balance Within a Tritium-Lean Target

- Initial tritium loading = 0.53% in 19.6 mg
  = 156 µg
  = 3.11 × 10^{19} tritons
- Fusion reactions:
  - # of D-D fusions = 5.01 × 10^{20} per target (2.51 × 10^{20} tritons created)
  - # of D-T fusions = 2.58 × 10^{20} per target (2.58 × 10^{20} tritons destroyed)
  - # of D-^{3}He fusions = 8.68 × 10^{19} per target
- Transmutation reactions:
  - D(n,γ)T = 4.85 × 10^{16} tritons created → 80% immediately burn
  - T(n,2n)D = 2.45 × 10^{17} tritons destroyed
  - ^{3}He(n,p)T = 1.92 × 10^{19} tritons created
- Overall tritium breeding:
  - Initial tritium = 3.11 × 10^{19} tritons/target
  - Final tritium = 4.31 × 10^{19} tritons/target
  - Tritium-lean target breeding ratio = 1.38
  - An additional 3.29 × 10^{18} tritons/target are created in (n,T) reactions in the B_2O_3 coolant
  - Overall tritium breeding ratio = 1.49

Due to self-sufficiency of the target, a breeding blanket would not be needed in a power plant utilizing tritium-lean targets.

Parameters for Comparing Tritium-Lean Power Plant to HYLIFE-II

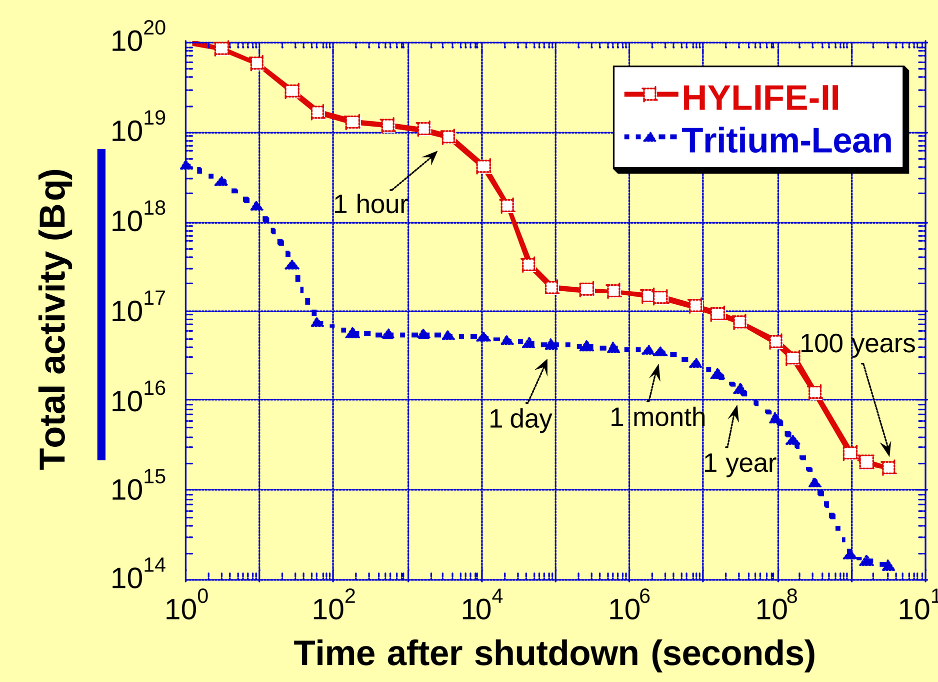
- HYLIFE-II uses thick-liquid Flibe protection scheme to make the first wall a lifetime component[8-10]:
  - Requires Flibe thickness of 56 cm for lifetime structures
  - Total thermal power is 2675 MW
  - Target yield is 353 MJ/6.4 Hz
  - 1-D tritium breeding ratio = 1.21
- Tritium-lean design can use an alternate liquid:
  - B_2O_3 is selected as an *example* due to its low activation - needs to be investigated
  - Requires a thickness of 40 cm for lifetime structures
  - Desire thermal power of 2675 MW:
    - Multiplication factor is 1.38
    - Fusion power of 1940 MW needed
    - Requires repetition rate of 1.5 Hz
- Both designs are modeled with stainless steel 304 (SS304) first wall at radius of 3.0 m
- Lower repetition rate would reduce pumping power, and thus, increase net electric output (credit not taken)



The high rr of the tritium-lean target leads to significant softening of the neutron spectrum and the net production of tritium.

Comparison of S&E Features of Tritium-Lean and HYLIFE-II Power Plants

- B_2O_3 coolant has lower activity than Flibe:
  - 200-300× lower from minutes-hours due to lack of ^{18}F
  - 5-10× lower beyond 12 hours
- Very low afterheat of B_2O_3/SS304 suggests that significant mobilization is highly unlikely:
  - B_2O_3 afterheat falls to ~ 2 watts within 10 minutes
  - First wall afterheat is ~ 6 kW during first 2-3 hours
- Waste management is significantly improved:
  - WDR slightly higher for B_2O_3 than Flibe (^{14}C production)
  - Tritium-lean first wall qualifies for disposal via SLB (6× lower than HYLIFE-II case)
  - Tritium-lean blanket structure has 14× lower WDR than HYLIFE-II case
  - Waste volumes are approximately equal in two designs
- Contact dose rates of tritium-lean design allow remote recycling of SS304 components in a reasonable period of time:
  - 10 mSv/hr dose rate limit assumed for remote recycling[11]
  - ^{60}Co dominates both designs
  - HYLIFE-II first wall and blanket require 100 and 65 years of cooling, respectively
  - Tritium-lean components require 70 and 32 years, respectively, by comparison
  - Recycling "limit" truly can be determined only with study of the ultimate use of the recycled material as well as the recycling process



Neutron attenuation within the target would significantly reduce the WDR of structural components in the tritium-lean design.

Component	Volume (m^3)	Waste disposal rating HYLIFE-II	T-Lean
Coolant	1240	2.24e-3	3.32e-3
First wall	0.36	1.51e+0	2.40e-1
Blanket	3.93	2.09e-2	1.49e-3

A power plant utilizing tritium-lean targets may offer significant S&E advantages over one using traditional targets.

Conclusions and Recommendations

- New target design work may increase the coupling efficiency to > 25% → tritium-lean targets would be viable with 4-5 MJ drivers if used with fast igniters
- Use of tritium-lean targets could lead to a significant (~ 100×) reduction in the target factory tritium inventory
  - Current inventories are believed to be 200 g - 4 kg for traditional target designs[12-13]
- Due to the tritium self-sufficiency of the target, designers would not be limited to use of lithium-bearing blanket materials → coolants could be selected for low-activation and to satisfy other design criteria (e.g., beam propagation, pumping power, power conversion, etc.)
- The high-density of tritium-lean targets attenuates much of the neutron energy within the capsule → radiation damage is reduced
- The tremendous S&E advantages that might be realized with tritium-lean targets suggests that such designs (and the fast igniter) should be pursued in earnest

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